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Abstract

Empirical analyses of firm behaviour typically assume that there is a stable relationship between investment on the one hand, and changes in the relative prices of inputs, output demand, and other determinants on the other hand. However, because of the lumpy nature and irreversibility of investments and the presence of uncertainty about future economic developments, a specific percentage change in relative prices and output demand may not always lead to the same percentage change in capital stocks. That means that different regimes may exist in investment behaviour. We test whether such regimes exist using high-quality data on eight manufacturing industries in the Netherlands. Three different regimes can be identified that are characterised by differences in the relative input price levels, and we find that if relative prices take on extreme values, the propensity to adjust the scale of production to changes in demand is very low.

Key words: Thresholds, investment behaviour, panel data, energy policy.

JEL-classification: C23, E22, Q43.

1. Introduction

This paper focuses on discontinuities in the investment relationship. The relevance of this analysis – for researchers and policy makers alike – is immediately clear when considering the past pattern of changes in the prices of two main variable inputs in production, labour and energy. From the early 1970s until the mid-1980s, the relative price of energy to the wage rate increased substantially, whereas after the mid-1980s this relative price dropped sharply. Typically, researchers have coped with this discontinuity by making either the regression equation's intercept or its elasticities time-dependent. Although such an approach may give a reasonably good fit for past investment behaviour, it is difficult to determine which coefficient values should be used for forecasting purposes. For instance, do firms expect the current energy price increases to be temporary or more permanent? By identifying thresholds that result in different investment regimes, we may be able to better analyse the future effects of energy saving policies. This is especially relevant for policy makers today because of the surge in energy prices as observed in the first half of the current decade.

Changes in output demand and changes in relative input prices are the main determinants of investment rates (e.g. Blanchard and Fischer 1989, p. 301; Abel 1990). Typically, empirical analyses are based on the implicit assumption that the relationships under investigation are stable over the estimation period (Berndt 1991, p. 277). In the case of energy policy modelling, however, Kuper and Van Soest (2003) argue that the parameters obtained from time–series estimation are not robust to rapid structural changes. Also the degree of energy price uncertainty may affect investment rates. Kuper and Van Soest (2006) show that higher levels of energy price uncertainty render changes in energy intensity more sluggish, because high uncertainty implies that there is a probability that energy price change reversals take place. The possibility of adverse price changes makes firms less willing to invest in new technologies (including, for example, energy saving equipment) because these investments may turn out to be unprofitable ex–post. They conclude that managing uncertainty should be high up on the policy agenda.[1]

[1] Pawlina and Kort (2004) discuss the effects on investment of policies aimed at managing uncertainty.

We search for discontinuities in investment behaviour using high-quality data on a panel of eight Dutch manufacturing industries over the period 1979-1994. We use industry data (as opposed to firm level data) because government policy tends to be industry generic rather than firm specific. The fact that we use fairly aggregated data imposes strong demands on the quality of especially the capital stock data series. Our decision to use the Netherlands' data set is motivated by exactly that consideration as capital is measured by means of detailed surveys rather than on the basis of Perpetual Inventory Methods. We apply Hansen's (1999) panel data threshold estimation procedure that allows us to estimate the threshold parameters demarcating the different regimes simultaneously with the other parameters. This approach has become quite popular,[2] however to the best of our knowledge the application is new to the field of energy economics. Our attempt to measure the threshold at which investment is triggered is advocated by Carruth et al. (2000) as a way to successfully test the relation between uncertainty and investment. We do find evidence for the existence of thresholds in terms of input prices. This implies that industry responsiveness to changes in its economic environment does depend on the value of input prices. Our findings suggest that uncertainty makes firms less responsive to increases in demand. Hence, firms invest less if uncertainty is high (see also Guiso and Parigi, 1999).

The set-up of the paper is as follows. In Section 2 we explain why investment behaviour can exhibit discontinuities. The focus is on the fixed-costs nature of investment (the existence of which implies that investments are, at least to some extent, irreversible) and on uncertainty. Section 3 explains the threshold estimation method used. In Section 4 threshold effects are estimated for eight sectors of the Dutch industry. Section 5 argues that the observed effects are not simply industry- and/or time-specific, but are indeed related to the value of energy prices. Section 6 concludes.

[2] See for instance Shen and Wang (2005) and Shen (2005). The latter allows for a smooth transition between regimes. Bo et al. (2006) apply the Hansen panel data estimation procedure in a threshold uncertainty model of investment.

2. Discontinuities in investment behaviour

The main hypothesis we wish to test in this paper is whether the same percentage change in each of the various variables influencing investment behaviour always result in the same percentage change in investment, irrespective of the absolute level of (relative) input prices, state of the economy, etc. We expect this hypothesis not to be supported by the data, because of the existence of fixed adjustment costs, irreversibility of investments and other indivisibilities in the investment process, financial constraints or a combination (see Holt, 2003).

There are two reasons why we expect the elasticities of investment with respect to either relative input prices or industry demand not be constant. First, we expect that changes in relative input prices or aggregate demand do not always induce firms to purchase new capital goods to adjust its input mix to the new relative price structure. Due to the fixed-costs nature of such adjustments and the irreversibility of investments, there is a range of relative prices and percentage increases in output demand for which the net present value of such an investment is negative. Hence, theory predicts that within that range, relative price changes do not result in changes in the composition of the capital stock.

Second, the responsiveness of firms with respect to changes in relative prices or aggregate demand may also be affected by uncertainty about future economic developments. Whereas at intermediate ('normal') levels of relative prices the technology choice is fairly easy, additional investments are more risky when relative prices take on more extreme values. Depending on whether the shocks in relative prices are expected to be only temporary or more permanent, the firm will select a technology that is either better equipped for the more 'normal' relative price levels or for the more extreme price levels currently observed. However, uncertainty with respect to the nature of the new price structure may be such that it is optimal to postpone increasing the scale of production, even though demand has increased (see also Bernanke, 1983). More information may be obtained (for example by just wait and see) before purchasing additional capital goods. If mean reversion is expected to be strong, uncertainty with respect to future prices is negligible and firms are equally responsive to relative price changes independent of the current relative price level. If divergence from the mean is more persistent, postponing the investment may be optimal. For an overview of the literature on investment under uncertainty and on the role of mean reversion, see Dixit and Pindyck (1994) or Pindyck (1991).

3. The threshold estimation model

Before discussing the data and the estimation results, we briefly explain the estimation procedure. We start from the assumption that changes in the variable input mix or in the scale of production require investments in new capital goods. We test for the existence of relative price ranges for which the responsiveness of industries to changes in market circumstances differs. If no thresholds are found to exist, we can reject the hypothesis that indivisibilities matter at the industry level and hence that the response of firms to changes in relative prices is the same over the entire estimation period. To avoid an arbitrary selection of relative price ranges we estimate an investment function using the threshold regression method with industry-specific fixed effects as proposed by Hansen (1999). The standard investment relation is adjusted to allow for, for example, two thresholds in the following way:[3]

$$y_{it} = \mu_i + \beta_1' x_{it} I(q_{it} \le \gamma_1) + \beta_2' x_{it} I(\gamma_1 < q_{it} \le \gamma_2) + \beta_3' x_{it} I(q_{it} > \gamma_2) + e_{it}, \qquad (1)$$

where subscripts i and t denote industries and time periods respectively, y_{it} is the growth rate of the stock of capital, i.e. net investment divided by the stock of capital, μ_i captures industry fixed effects, x_{it} is a vector of k explanatory variables, q_{it} is the threshold variable, γ_1 and γ_2 are the thresholds, and I is an indicator function that has a value one if its argument is true and zero otherwise. Therefore, the elasticities with respect to the explanatory variables are regime-dependent as the coefficient vectors β_j (j=1,…,3) are allowed to differ. The variables x_{it} and q_{it} as used in our application are defined below. The error term is i.i.d. with mean zero and finite variance, which rules out lagged dependent variables.

[3] Note that the specification of equation (1) allows for two thresholds and hence is able to discern three regimes, but obviously the specification can easily be changed in order to allow for any number of thresholds.

The threshold is estimated using conditional least squares. The observations are first sorted on the threshold variable. The sum of squared residuals is computed for all values of the threshold variable. The optimal value of the threshold is the value that minimises the sum of squared residuals. Bootstrapping simulates the asymptotic distribution of the likelihood ratio test that is used to determine whether the threshold effect is statistically significant under the null of no threshold, i.e. a linear investment model. We use 300 bootstrap replications to construct asymptotically valid p-values. If the null is rejected, similar tests are used to determine whether there are one, two or even more thresholds.

4. Estimation results

We use a panel of eight Dutch manufacturing industries and our estimation period covers 1979-1994, the longest time period (sixteen years) for which a consistent and balanced data set is available for the Netherlands (see Appendix A). Unfortunately, this high quality set is discontinued. This period covers a period of energy price increases as well as a period in which energy prices dropped again.

The inputs of production are labour, energy and capital. The 3-dimensional vector of explanatory variables (x_{it}) consists of the rates of growth of two relevant relative prices (the ratio of the user cost of capital and the wage rate, R/W, and the ratio of the price of energy and the wage rate, P_E/W)[4], and the growth rate of gross value added (X). We carefully constructed the rental price of capital as capital income (in current prices) resulting from production (which is given by the gross operating surplus corrected for wage income of self-employed) divided by the capital stock.

Thus, the reduced-form equation (1) captures a substitution effect as well as an accelerator effect, and accounts for the (relative) costliness of investments through the inclusion of the cost of capital. Before testing for the existence of thresholds, we first present the results for two linear models. Model (a)

[4] As capital and energy are often found to be complements, we use the wage rate as a deflator of the rental price of capital (see Kemfert 1998).

assumes constant parameters, whereas Model (b) includes an interaction term between the price of energy divided by the wage rate[5] and the growth rate of gross value added. Other combinations of interaction terms were not significant. These linear models assume no thresholds and thus serve as benchmark models. The industry-specific fixed effects pick up the rate of depreciation, so that the dependent variable can be interpreted as gross investment over the stock of capital. The results are in Table 1.

<Insert Table 1 about here>

The rate of growth of the rental price of capital relative to the wage rate (*R/W*) is not found to be significant at 5%. However, the rate of growth of the relative price of energy as well as the percentage increase in output demand are found to positively and significantly affect the rate of growth of capital. Model (b) indicates that the effect of the rate of growth of value added on investment is not constant but depends of the relative price of energy.

The regression results presented in Table 1 indicate that not all parameters are constant, that is independent for instance of whether the price of energy relative to the wage rate is high or low. However, the second model does not identify different regimes. Let us now allow the elasticities to differ between regimes, where the thresholds demarcating these regimes are estimated jointly with all other coefficients of the model.

Our threshold variable is the relative price of the variable inputs (calculated as the energy price divided by the wage rate; that is, $q_{it}=P_E/W$). The hypothesis is that firms respond differently when relative prices take on extreme values. In principle the coefficients for all elements of vector x_{it} may be regime-dependent, i.e. dependent on the threshold variable. The threshold variable is lagged one period for statistical reasons. An economic argument might be that it takes time to order and install new capital goods. In our search for thresholds, we tested for the existence of up to three thresholds for all three

[5] This price ratio is lagged one period based on statistical grounds.

explanatory variables (the accelerator X, the relative variable input price P_E/W and the relative rental price of capital R/W). We did not find evidence for thresholds for the two relative price variables, which implies that the impact of changes in these prices on investment behaviour is not regime-dependent. However, there is strong evidence for the existence of thresholds when considering the accelerator effect. For this variable, the null of no thresholds is rejected at the 5% significance level. The actual number of thresholds is found to be two: the F-statistic testing the possibility of one versus two thresholds equals 14.1. Using bootstrapped critical values we can reject the null of one threshold at a 1% level of significance in favour of the two threshold hypothesis. Finally, we do not reject the null of two thresholds versus three thresholds (the associated p-value is about 0.12).

The existence of the two thresholds can also be illustrated graphically. Figures 1 and 2 show the values of the Likelihood Ratio tests for the first threshold (γ_1) and second threshold (γ_2), respectively. The optimal threshold values are those for which the Likelihood Ratio test is equal to zero, and the dotted horizontal lines identify the 95% confidence intervals around the thresholds' point estimates. The two point estimates are 1.41 and 2.60, and the associated 95% confidence intervals are [1.32, 2.29] and [2.49, 2.76]. The confidence intervals do not overlap, so we do find three different regimes.

<Insert Figures 1 and 2 about here>

Given the existence of three regimes for the accelerator and the absence of thresholds for the other two explanatory variables, we can now present the coefficient values of the investment equation (1). The relative price of energy is found to be positive and significant, as can be seen from the second row in Table 2. The fact that there is no evidence for the existence of thresholds for this explanatory variable implies that its coefficient does not differ significantly across the regimes. The rental price of capital relative to the wage rate (R/W) is not found to be significant at 5%. The elasticities for the accelerator in the different regimes are presented in the bottom three rows. The responsiveness of investments to changes in demand is much higher in the intermediate range of the thresholds ($1.41 < P_E/W \leq 2.60$)

than for regions where the relative energy price is very high ($P_E/W > 2.60$) or very low ($P_E/W \leq 1.41$). If the price of energy relative to the wage rate is between 1.41 and 2.60, the accelerator is highly significant.

<Insert Table 2 about here>

5. Discussion

Our findings indicate that the rental price of capital is not an important determinant for investment behaviour. Moreover, the relative price of energy with respect to labour does affect the propensity to invest throughout the sample. Furthermore, increases in the demand for output (X) only result in net increases in periods where the relative variable input prices are at an intermediate level. Thus, in periods where the relative price takes on a more extreme value, only relative price changes trigger additional investments to adjust the input mix, whereas changes in industry demand do not result in significant changes in the capital stock. Although we cannot test what causes this latter result, it is helpful to realise that changes in the relative price of energy with respect to labour are driven by the energy price. The wage rate increases gradually, whereas the development of the energy price is much more volatile.[6] So, one explanation for the different regimes might be that in periods of extreme energy prices there is too much uncertainty to warrant additional investments in response to demand fluctuations (see also Kuper and Van Soest, 2006). Additional investments, if any, do not arise from increased demand but from firms adjusting the energy intensity of production.

One might argue that the observed effects can simply be captured if we allow the accelerator's coefficient to be industry- and/or time-specific. For instance, the business cycle coincides with specific relative price levels, which explains the observation that industry demand triggers investments in some periods but not in others. Similarly, not all industries pay the same prices for their inputs (especially

[6] The coefficient of variation of the rate of growth of energy prices equals10.7 while the coefficient of variation of the rate of growth of the wage rate is 0.7.

labour and energy). Therefore, industries that face intermediate levels of relative prices, simply exhibit a different type of investment behaviour than industries that either pay very high or very low energy prices (as compared to the wage rate). Inspection of the number of observations that fall in the three regimes for each year and industry gives insight into the validity of these arguments. Table 3 shows that to a certain extent, the thresholds capture the past pattern of relative price changes. More specifically, the first regime is found to coincide with post-1986 observations whereas the third is found to coincide with the pre-1986 period. Therefore, this analysis indicates that there is a structural break in investment behaviour between the period of high and increasing relative energy prices (the first period) and that of lower, relatively stable relative energy prices (the second period). However, simply imposing a dummy to capture that break will not do, as the second regime (in which the accelerator is found to be particularly important) exists in both subperiods, albeit slightly more dominant in the post-1986 period than in the preceding one.

<Insert Table 3 about here>

The thresholds might also reflect differences in industry behaviour rather than point at more structural differences. However, Table 4 rules out this possibility. All observations of the energy-intensive sectors fall in the lower two regimes, whereas the bulk of the other six sectors occur in the higher two regimes. So, although we find that relatively energy-intensive industries (chemicals and the basic metal industry) generally face lower relative energy prices than do the other industries, the number of observations for each of the two groups falls for about 50% in the middle regime. Consequently, it is not simply the case that - in response to changes in industry demand - relatively energy-extensive industries would be more apt to invest than the relatively intensive ones. This would have been the case if, for example, all observations of the latter were concentrated in the lower relative price regime.

<Insert Table 4 about here>

Rejecting these alternative explanations leads us to the conclusion that only in periods of relatively stable energy prices demand fluctuations lead to additional investments. Demand fluctuations do not induce higher investment if energy price changes are more extreme. However, in either case energy price changes do effect investments directly, but the nature of these investments may differ across regimes.

6. Conclusion

The main driving forces of investments in new technologies are changes in the demand for the firm's or industry's output and changes in relative variable input prices. In this paper we argue that the elasticities of these explanatory variables may not be constant over time due to, for example, uncertainty about future market circumstances and the fixed-cost nature of investments. We use Hansen's (1999) threshold estimation procedure to determine whether discontinuities in investment behaviour exist using a data set of eight Dutch manufacturing industries for the period 1979-1994. The data set is rather short because the high quality data set we use in this paper is discontinued and can not be extended to cover more recent years.

We find that the propensity to invest in response to changes in relative input prices is about constant over the entire estimation period. However, we identify three regimes with different responses on investment to changes in output demand. We find that if relative prices take on extreme values, the propensity to adjust the scale of production to changes in demand is very low. These relative price changes are caused by changes in energy prices because the wage rate develops rather gradually.

The implications for the current situation of high and volatile energy prices are clear. Firms do not expand their production capacity if demand increases. Our conjecture is that in periods of extreme relative prices, for instance relative high energy prices, there is too much uncertainty about the future energy prices to warrant additional investments in response to demand fluctuations. If energy price uncertainty could be reduced, firms would be more inclined to expand capacity and invest in new, energy-saving, equipment even in periods when energy prices are high.

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Appendix A Data

Our data panel covers eight sectors of industry for the Dutch economy: agriculture, food and beverages, textiles and clothing, paper industry, basic metal industry, building materials, chemical industry and construction. These sectors are chosen on the basis of data availability for a longer time period. Data on energy use and energy prices are not (yet) available for the period before 1973 and after 1994 consistent with the 1973-1994 period. Furthermore, not all variables are available for the chemical industry for the period 1973-1976, so we restricted the time period to the period 1977-1994.

There are three main sources of the data. Volumes and prices of value added and labour are taken from the P-series of the *National Accounts 1997* of CBS Statistics Netherlands (1998). The CPB Netherlands Bureau for Economic Policy Analysis provided data on the stock of capital in 1990 prices. Data on the use of energy and the price of energy are based on the publication *De Nederlandse Energiehuishouding* of the CBS. Based on these data, we have constructed the rental price of capital as capital income (in current prices) resulting from production (which is given by the gross operating surplus corrected for wage income of self-employed) divided by the capital stock.

Table 1. The linear model estimates for the investment function (dependent variable is $\Delta\log(K)$; Hubert-White robust standard errors are presented in parenthesis; industry-specific fixed effects are not shown).

	Model (a)	Model (b)
Regressor	Coefficient	Coefficient
$\Delta\log(R/W)$	0.037	0.033
	(0.021)	(0.019)
$\Delta\log(P_E/W)$	0.035^{*}	0.040^{**}
	(0.014)	(0.015)
$\Delta\log(X)$	0.181^{**}	0.584^{**}
	(0.064)	(0.161)
$(P_E/W)_{-1} \times \Delta\log(X)$	-	-0.166^{**}
		(0.058)
Number of Observations	128	128
Sum of Squared Errors	0.143	0.125

*Significant at the 5% level

**Significant at the 1% level.

Table 2. Double threshold model estimates for the investment function (dependent variable is $\Delta\log(K)$; Hubert-White robust standard errors are presented in parenthesis; industry-specific fixed effects are not shown).

Regressor	Coefficient
$\Delta\log(R/W)$	0.023
	(0.018)
$\Delta\log(P_E/W)$	0.026*
	(0.012)
$\Delta\log(X) \times I[(P_E/W)_{-1} \leq 1.41]$	0.017
	(0.044)
$\Delta\log(X) \times I[1.41<[(P_E/W)_{-1} \leq 2.60]$	0.498**
	(0.102)
$\Delta\log(X) \times I[[(P_E/W)_{-1} > 2.60]$	0.028
	(0.082)
Number of Observations	128
Sum of Squared Errors	0.119

*Significant at the 5% level

**Significant at the 1% level.

Table 3. Number of observations per year in each regime.

Year	$I(P_E/W \leq 1.41)$	$I(1.41 < P_E/W \leq 2.60)$	$I(P_E/W > 2.60)$	Total
	Regime			
1979		7	1	8
1980		3	5	8
1981		2	6	8
1982		2	6	8
1983		2	6	8
1984		2	6	8
1985		2	6	8
1986		7	1	8
1987	2	6		8
1988	2	6		8
1989	2	6		8
1990	2	6		8
1991	2	6		8
1992	4	4		8
1993	3	5		8
1994	5	3		8
Total	22	69	37	128

Table 4. Number of observations per sector in each regime.

	Regime			
	$I(P_E/W \leq 1.41)$	$I(1.41 < P_E/W \leq 2.60)$	$I(P_E/W > 2.60)$	Total
Agriculture		8	8	16
Textiles and clothing		10	6	16
Building materials		10	6	16
Construction	1	10	5	16
Food and beverages	2	8	6	16
Paper industry	3	7	6	16
Chemical industry	8	8		16
Basic metal industry	8	8		16
Total	22	69	37	128

Figure 1. Confidence interval construction in a double threshold model.

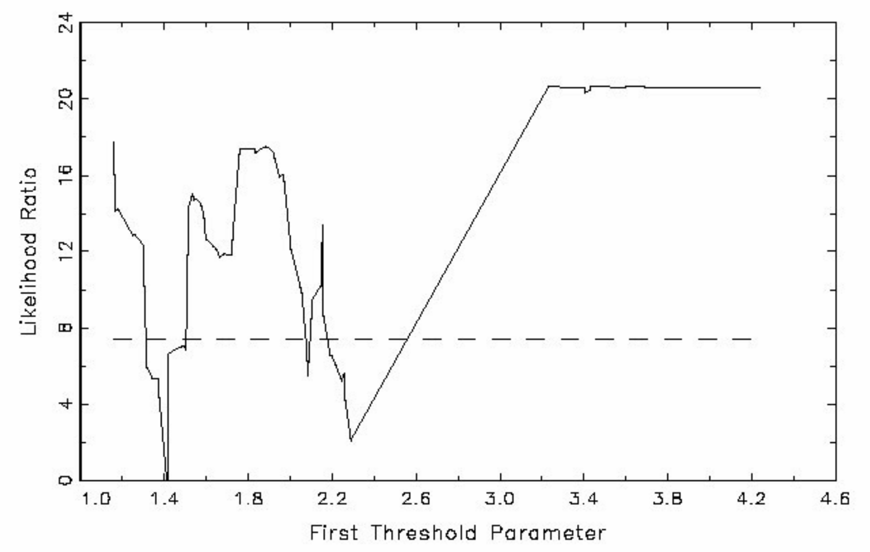

Figure 2. Confidence interval construction in a double threshold model.